PERFORMANCE ANALYSIS OF SINGLE PHASE GRID CONNECTED FOR PV INVERTER USING PR CONTROLLER WITH DIFFERENT FILTERS

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I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Oleh kerana PV menghasilkan voltan DC, penyambung grid yang disambungkan adalah penting untuk memadankan voltan AC yang ditukar dengan voltan grid AC yang asli. Kelemahan utama penyongsang adalah gangguan harmonik disebabkan oleh penukaran semasa penukaran yang sensitif terhadap beban yang disambungkan. Baru-baru ini, penapis LCL lebih disukai berbanding dengan penapis L dan penapis LC, untuk sambungan ke grid kerana pelepasan harmonik yang baik dihasilkan oleh penyongsang PV yang bersambung dengan grid. Walau bagaimanapun, resonans yang wujud dalam penapis LCL adalah salah satu yang mencabar untuk operasi sistem yang stabil. Untuk meminimumkan kehilangan kuasa, tambahan penampan aktif boleh digunakan selari dengan C sahaja. Secara konvensional, pengawal PI atau PID adalah pengawal semasa biasa yang digunakan dalam penyongsang PV kerana kesederhanaannya, tetapi kekurangan di dalam keupayaan penyegerakan voltan AC dan kesilapan keadaan mantap. Akhir-akhir ini, kemajuan pengendali semasa proporsional-resonance (PR) untuk melakukan penyongsang PV yang bersambung grid secara efisien untuk menggantikan pengawal semasa PI konvensional dalam mengawal kualiti arus dan voltan grid telah menjadi minat dalam pembentukan penyambung PV yang berkaitan grid. Walau bagaimanapun, kerana besar pemalar yang tidak terhingga pengawal PR membawa kepada kesukaran untuk melaksanakan sama ada untuk pengawal analog atau digital. Oleh itu, pengawal PR yang diubah suai dicadangkan dengan tujuan untuk mendapatkan prestasi penyongsang PV yang menjanjikan. Dalam tesis ini, satu sistem penyongsang PV yang disambungkan grid direka dan dibangunkan dengan menggunakan pengawal semasa PR yang diubah suai dengan penapis LCL yang aktif. Kemudian, prestasi sistem penyongsang PV yang disambungkan grid dianalisis, disiasat dan disahkan melalui simulasi menggunakan MATLAB / Simulink di bawah gangguan faktor-faktor gangguan bebanan dan kekerapan frekuensi. Kesimpulan total harmonik (THD) diambil dan dibandingkan dengan semua penapis menggunakan PI dan pengawal PR yang diubah suaikan. Tanggapan frekuensi penyambung PV yang berkaitan grid dengan penapis dianalisis dan dibandingkan menggunakan pendekatan Diagram Bode untuk analisis ketahanan atau kestabilan. Keputusan menunjukkan bahawa pengawal yang dicadangkan mempunyai persembahan yang lebih baik semasa gangguan voltan dan kekerapan frekuensi daripada pengawal semasa PI. Dari analisis THD, penapis LCL dengan aktif pemampan mempunyai harmonik yang kurang dalam arus keluaran berbanding dengan penapis lain. Jumlah THD semasa penapis LCL yang aktif dengan pengawal PR yang dicadangkan apabila gangguan voltan dan kekerapan frekuensi adalah 0.43% dan 0.46%, masing-masing. Akhir sekali, dalam analisis kestabilan tindak balas frekuensi telah menunjukkan bahawa peyongsangan PV yang disambung grid menggunakan cadangan pengawal dan penapis lebih stabil daripada penapis dan pengawal PI yang lain.

ABSTRACT

Since the PV producing a DC voltage, the grid-connected inverter is essential for matching the converted AC voltage with a purely AC grid voltage. The main drawback of the inverter is the harmonic distortion due to the switching during the conversion that is sensitive to the connected loads. Recently, the LCL filter is preferred compared to L filter and LC filter, for interfacing to the grid due to a good attenuate capacity of high order harmonics produced by grid-connected PV inverter. Nonetheless, the inherent resonance of the LCL filter is one of the challenging for stable operation of the system. To minimize the power losses, the damping can be applied to series with C only. Conventionally, the PI or PID controllers are the common current controller used in PV inverter due to its simplicities, but the lack of ability for AC voltage synchronization, steady-state errors and limited disturbance elimination capability. Lately, the advancement of proportional-resonance (PR) current controller to perform an efficient grid-connected PV inverter to replace the conventional PI current controller in regulating the quality of grid current and voltage has become interested in designing grid-connected PV inverter. However, due to an infinite gain of the PR controller leads to difficulty implementing in either analogue or digital controller. Therefore, a non-ideal of PR controller is proposed in purpose to get promising performances of PV inverter. In this thesis, the single-phase grid-connected PV inverter system is designed and developed by applying a proposed non-ideal PR current controller with LCL filter active damping. Then, the performance of the proposed grid-connected PV inverter system is analysed, investigated and verified through simulation using MATLAB/Simulink under disturbances factors of voltage sag and frequency distortion. The total harmonic distortion (THD) is captured and compared with all filters using PI and non-ideal PR controllers. The frequency response of the grid-connected PV inverter with filters are analysed and compared using the Bode Diagram approach for robustness or stability analysis. The results show that the proposed controller has better performances during voltage sag and frequency distortion than the PI current controller. From THD analysis, it is absorbed that the LCL filter active damping has less harmonic in the output current compared with other filters. The current THD of LCL filter active damping with the proposed PR controller when voltage sag and frequency distortions are 0.43% and 0.46%, respectively. Lastly, in the stability analysis of frequency responses had shown that the proposed grid-connected PV inverter performed more stable than other filters and PI controller.

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LIST OF SYMBOLS

θ	Phase Of Reference
θ’	Output Signal
ω_c	Bandwidth Around The Ac Frequency
ω_o	Resonant Frequency
C_{dc}	DC Link Capacitor
C_{f2}, C_{f3}	Filter Capacitor
C_{pv}	Capacitor Of PV Cell
D	Duty Cycle
ε	Phase Error
E_{GO}	Band Gap Energy Of The Semiconductor
f_o	Fundamental Frequency
f_{res}	Resonant Frequency
f_s	Switching Frequency
I_m	Maximum Power Point Current
I_n	RMS Current
I_{or}	PV Cell’s Reverse Saturation Current At Temperature T_r
I_{PH}	Photon Current
I_{ref}	Reference Current
I_{SC}	Short Circuit Voltage
I_{SCR}	Short Circuit Current At STC
k	Boltzmann’s Constant
K_I	Integral Gain
K_P	Proportional Gain
K_1	Temperature Coefficient Of The Short-Circuit
L	Inductor
L_{g3}	Grid Inductor
L_{i1}, L_{i2}, L_{i3}	Inverter Inductor
m_a	Amplitude Modulation Ratio
N_p	Number of Cells Connected in Parallel
N_s	Number of Cells Connected in Series
P_m	Maximum Power Point Power

q	Electron Charge
R_d	Damping Resistor
R_s	Series Resistance
R_{sh}	Shunt Resistance
S	Operating Solar Radiation
S_{ref}	Reference Solar Radiation
S_1, S_2, S_3, S_4	Switches
T_r	PV Cell Absolute Temperature At STC (Standard Test Condition)
T_{ref}	Reference Temperature
$V_{control}$	Control Signal
V_{dc}	DC Bus Voltage
V^*_{dc}	Reference DC Bus Voltage
V_g	Grid Voltage
V_m	Maximum Power Point Voltage
V_{OC}	Open Circuit Voltage
V_r	Reference Waveform
V_{tri}	Triangular Waveform

LIST OF ABBREVIATION

AC	Alternating Current
APFs	Active Power Filters
APR	Adaptive Proportional Resonant
CHCC	Conventional Hysteresis Current Controller
CNMPC	Continuous Nonlinear Model Predictive Control
CSI	Current Source Inverter
DC	Direct Current
EMI	Electromagnetic Interference
FLC	Fuzzy Logic Controller
HB	Hysteresis Band
HC	Harmonic Compensator
HCC	Hysteresis Current Control
IC	Incremental Conductance
LF	Loop Filter
MAC	Model Algorithm Control
MHCC	Modified Hysteresis Current Controller
MPC	Model Predictive Control
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
PD	Proportional-Derivative
PI	Proportional Integral
PID	Proportional-Integral-Derivative
PLL	Phase-Locked Loop
P&O	Perturbation and Observation
PR	Proportional Resonant
PV	Photovoltaic
PWM	Pulse Width Modulation
RE	Renewable Energy
SPWM	Sinusoidal Pulse Width Modulation
STC	Standard Test Conditions
THD	Total Harmonic Distortion

VCO	Voltage Control Oscillator
VSI	Voltage Source Inverter

REFERENCES

Abdool, A., & Alwannan, K. (2014). Current Harmonic Generation of a Modeled and Simulated Single Phase Grid Connected PWM Current Controlled Photovoltaic Inverter. *First International Conference on Green Energy (ICGE)*, 89–95.

Abdulkadir, M., Samosir, A. S., & Yatim, A. H. M. (2012). Modeling and Simulation Based Approach of Photovoltaic System in Simulink Model. *ARPN Journal of Engineering and Applied Sciences*, *7*(5), 616–623.

Agrawal, S., Sekhar, P. C., & Mishra, S. (2013). Control of Single-Phase Grid Connected PV Power Plant for Real as well as Rective Power Feeding. *IEEE International Conference on Control Applications (CCA) at Hyderabad, India*, 5–10.

Alajmi, B. N., Ahmed, K. H., Adam, G. P., & Williams, B. W. (2013). Single-Phase Single-Stage Transformer less Grid-Conected PV System. *IEEE Transactions on Power Electronics*, *28*(6), 2664–2676.

Althobaiti, A., Armstrong, M., & Elgendy, M. A. (2016). Current Control of Three-phase Grid-connected PV Inverters using Adaptive PR Controller. *IEEE International Renewable Energy Congress (IREC) at Hammamet, Tunisia*.

Altin, N. (2012). Single Phase Grid Interactive PV System With MPPT Capability Based on Type-2 Fuzzy Logic Systems. *IEEE International Conference on Renewable Energy Research and Applications (ICRERA) at Nagasaki, Japan*, 1–6.

Aouadi, C., Abouloifa, A., Hamdoun, A., & Boussairi, Y. (2014). Advanced Nonlinear Control of Photovoltaic System Connected to the Grid. *IEEE Conference on Complex Systems (WCCS) at Agadir, Morocco*, 0–5.

Aouadi, C., Abouloifa, A., Hamdoun, A., & Boussairi, Y. (2015). Nonlinear controller Design for Single-Phase Grid-Connected Photovoltaic Systems. *IEEE Australian Control Conference (AUCC)*, 1–5.

Aquila, R. V. D., Balboni, L., & Morici, R. (2010). A New Approach : Modeling, Simulation, Development and Implementation of a Commercial Grid-Connected Transformerless PV Inverter. *IEEE International Symposium on Power Electronics Electrical Drives Automation and Motion (SPEEDAM) at Pisa, Italy*, 1422–1429.

Bao, C., Ruan, X., Wang, X., Li, W., Pan, D., & Weng, K. (2012). Design of Injected Grid Current Regulator and Capacitor-Current-Feedback Active-Damping for LCL -Type Grid-Connected Inverter. *IEEE Energy Conversion Congress and Exposition (ECCE) at Raleigh, NC, USA*, 579–586.

Bikaneria, J., Joshi, S. P., & Joshi, A. R. (2013). Modeling and Simulation of PV Cell using One-diode model. *International Journal of Scientific and Research Publications*, *3*(10), 1–4.

Boonmee, C., & Kumsuwan, Y. (2013). Modified Maximum Power Point Tracking Based-on Ripple Correlation Control Application for Single-Phase VSI Grid-Connected PV Systems. *IEEE International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON) at Krabi, Thailand*.

Cao, D., Jiang, S., Yu, X., & Peng, F. Z. (2011). Low-Cost Semi-Z-source Inverter for Single-Phase. *IEEE Transactions on Power Electronics*, *26*(12), 3514–3523.

Caro, S. De, Scimone, T., Testa, A., Cacciato, M., & Scarcella, G. (2014). A NPC Transformerless Single Phase Inverter with Inner Voltage Boosting Capability. *IEEE International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM) at Ischia, Italy*, 653–658.

Casadei, D., Grandi, G., & Rossi, C. (2006). Single-Phase Single-Stage Photovoltaic Generation System Based on a Ripple Correlation Control Maximum Power Point Tracking. *IEEE Transactions on Energy Conversion*, *21*(2), 562–568.

Cha, H., & Vu, T.-K. (2010). Comparative Analysis of Low-pass Output Filter for Single-Phase Grid-connected Photovoltaic Inverter. *IEEE Applied Power Electronics Conference and Exposition (APEC) at Palm Springs, CA, USA*, 1659–1665.

Cha, H., Vu, T.-K., & Kim, J.-E. (2009). Design and Control of Proportional-Resonant Controller Based Photovoltaic Power Conditioning System. *IEEE Energy Conversion Congress and Exposition (ECCE)*, 2198–2205.

Chakraborty, S., Hasan, W., & Billah, S. M. B. (2014). Design and Analysis of a Transformer-Less Single-Phase Grid-Tie Photovoltaic Inverter Using Boost Converter with Immittance Conversion Topology. *IEEE International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT) at Dhaka, Bangladesh*.

Channegowda, P., & John, V. (2010). Filter Optimization for Grid Interactive Voltage Source Inverters. *IEEE Transactions on Industrial Electronics*, *57*(12), 4106–4114.

Chatterjee, A., & Mohanty, K. B. (2014a). Development of Stationary Frame PR Current Controller for Performance Improvement of Grid Tied PV Inverters. *IEEE International Conference on Industrial and Information Systems (ICIIS) at Gwalior, India*.

Chatterjee, A., & Mohanty, K. B. (2014b). Design and Analysis of Stationary Frame PR Current Controller for Performance Improvement of Grid Tied PV Inverters. *IEEE India International Conference on Power Electronics (IICPE)*.

Chen, Y., & Smedley, K. M. (2004). A Cost-Effective Single-Stage Inverter With Maximum Power Point Tracking. *IEEE Transactions on Power Electronics*, *19*(5), 1289–1294.

Chowdhury, A. S. K., & Razzak, M. A. (2013). Single Phase Grid-Connected Photovoltaic Inverter for Residential Application with Maximum Power Point Tracking. *IEEE International Conference on Informatics, Electronics & Vision (ICIEV) at Dhaka, Bangladesh*, 1–6.

Ciobotaru, M., Teodorescu, R., & Blaabjerg, F. (2005). Control of Single-Stage Single-Phase PV inverter. *IEEE Power Electronics and Applications*, 1–10.

Cui, W., Yang, B., Zhao, Y., Li, W., & He, X. (2011). A Novel Single-Phase Transformerless Grid-connected Inverter. *IEEE Industrial Electronics Society at Melbourne, VIC, Australia*, (50907058), 4–8.

Dai, X., & Chao, Q. (2009). The Research of Photovoltaic Grid-Connected Inverter Based on Adaptive Current Hysteresis Band Control Scheme. *IEEE International Conference on Sustainable Power Generation and Supply (SUPERGEN) at Nanjing, China*.

Das, M., & Agarwal, V. (2011). Novel PV Fed Three Phase Single Power Stage System for Stand-Alone Applications. *IEEE Photovoltaic Specialists Conference (PVSC) at Austin, TX, USA*, 1405–1410.

Davoodnezhad, R., Holmes, D. G., & Mcgrath, B. P. (2014). A Fully Digital Hysteresis Current Controller for Current Regulation of Grid Connected PV Inverters. *IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG) at Galway, Ireland*.

Devaraj, D., Sakthivel, S., & Punitha, K. (2011). Modeling of Photovoltaic Array and Simulation of Adaptive Hysteresis Current Controlled Inverter for Solar Application. *IEEE International Conference on Electronics Computer Technology (ICECT) at Kanyakumari, India*, 302–306. doi:10.1109/ICECTECH.2011.5942103

Elshaer, M., Mohamed, A., & Mohammed, O. (2010). Smart Optimal Control of DC-DC Boost Converter in PV Systems. *IEEE/PES Transmission and Distribution Conference and Exposition: Latin America*, 403–410.

Erdem, H. (2007). Comparison of Fuzzy , PI and Fixed Frequency Sliding Mode Controller For DC-DC Converters. *IEEE Electrical Machines and Power Electronics*.

Errouissi, R., Muyeen, S. M., Al-durra, A., & Leng, S. (2016). Experimental Validation of a Robust Continuous Nonlinear Model Predictive Control Based Grid-Interlinked Photovoltaic Inverter. *IEEE Transactions on Industrial Electronics*, *63*(7), 4495–4505.

Fadil, H. El, Giri, F., & Guerrero, J. M. (2012). Grid-Connected of Photovoltaic Module Using Nonlinear Control. *IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG) at Aalborg, Denmark*, 119–124.

Femia, N., Petrone, G., Spagnuolo, G., & Vitelli, M. (2005). Optimization of Perturb and Observe Maximum Power Point Tracking Method. *IEEE Transactions on Power Electronics*, *20*(4), 963–973.

Gaafar, M. A., & Shoyama, M. (2014). Active Damping for Grid-Connected LCL Filter Based on Optimum Controller Design Using Injected Grid Current Feedback Only. *IEEE Energy Conversion Congress and Exposition (ECCE) at Pittsburgh, PA, USA*, 3628–3633.

Gao, F., Li, D., Loh, P. C., Tang, Y., & Wang, P. (2009). Indirect DC-Link Voltage Control of Two-Stage Single-Phase PV Inverter. *IEEE Energy Conversion Congress and Exposition (ECCE) at San Jose, CA, USA*, 1166–1172.

Gupta, A., Porippireddi, A., Srinivasa, V. U., Sharma, A., & Kadam, M. (2012). Comparative Study of Single Phase PLL Algorithms for Grid Synchronization Applications. *International Journal of Electronics and Communication Technology*, *7109*, 237–245.

Hamad, M. S., Fahmy, A. M., & Abdel-Geliel, M. (2013). Power Quality Improvement of a Single-Phase Grid- Connected PV System with Fuzzy MPPT Controller. *IEEE Conference on Industrial Electronics Society at Vienna, Austria*, 1839–1844.

Hamid, M. I., Anwari, M., Salam, Z., & Taufik. (2008). Load Sharing Characteristic of Single Phase PV Inverter Connected to Grid. *IEEE International Conference on Power and Energy (PECon) at Johor Bahru, Malaysia*, (PECon 08), 1672–1676.

Hamzeh, M., Karimi, Y., Asadi, E., & Oraee, H. (2014). Design and Implementation of a Single Phase Grid Connected PV Inverter With a New Active Damping Strategy. *Power Electronics, Drive Systems and Technologies Conference (PEDSTC) at Tehran, Iran*, 72–77.

He, F., Zhoa, Z., Yuan, L., & Lu, S. (2011). A DC-link Voltage Control Scheme for Single-Phase Grid-Connected PV Inverters. *IEEE Energy Conversion Congress and Exposition (ECCE) at Phoenix, AZ, USA*, (50737002), 3941–3945.

Hosseini, S. H., Danyali, S., & Goharrizi, A. Y. (2009). Single Stage Single Phase Series Grid Connected PV System for Voltage Compensation and Power Supply. *IEEE Power & Energy Society (PES) at Calgary, AB, Canada*, 1–7.

Houari, A., Renaudineau, H., Nahid-mobarakeh, B., Martin, J., Pierfederici, S., & Meibody-tabar, F. (2014). Large Signal Stability Analysis and Stabilization of Converters Connected to Grid Through LCL Filters. *IEEE Transactions on Industrial Electronics*, *61*(12), 6507–6516.

Huang, M., Wang, X., Loh, P. C., Blaabjerg, F., & Wu, W. (2014). Stability Analysis and Active Damping for LLCL -Filter-Based Grid-Connected Inverters. *IEEJ Journal of Industry Applications*, *4*(3), 187–195.

Isen, E. (2016). Modelling and Simulation of Hysteresis Current Modelling and Simulation of Hysteresis Current Controlled Single-Phase Grid-Connected

Inverter. *International Conference on Electrical and Power Engineering (ICEPE) at Amsterdam*, (August 2015).

Jahanbakhshi, M., Asaei, B., & Farhangi, B. (2015). A Novel Deadbeat Controller for Single Phase PV Grid Connected Inverters. *IEEE Iranian Conference on Electrical Engineering (ICEE)*, 1613–1617.

Jena, S., Behera, P. R., & Panigrahi, C. K. (2015). Modified Hysteresis Current-Controlled PWM Strategy for Single Phase Grid Connected Inverters. *IEEE Power, Communication and Information Technology Conference (PCITC) at Bhubaneswar, India*.

Jianhua, W., Jing, Z., Longfei, L., Cong, T., & Le, Y. (2012). Predictive Control Based on Analytic Model for PV Grid-connected Inverters. *IEEE Chinese Control and Decision Conference (CCDC) at Taiyuan, China*, 4295–4299.

Kahrobaeian, A., & Farhangi, S. (2010). Stationary Frame Current Control of Single Phase Grid Connected PV Inverters. *IEEE Power Electronic & Drive Systems & Technologies Conference (PEDSTC) at Tehran, Iran*, 435–438.

Karshenas, H. R., & Saghafi, H. (2006). Performance Investigation of LCL Filters in Grid Connected Converters. *IEEE/PES Transmission & Distribution Conference and Exposition at Caracas, Venezuela*, *00*, 1–6.

Khalfalla, H., Ethni, S., Al-greer, M., Pickert, V., & Phan, V. T. (2016). An Adaptive Proportional Resonant Controller for Single Phase PV Grid Connected Inverter Based on Band-Pass Filter Technique. *IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG) at Cadiz, Spain*, 436–441.

Krimadinata, Abd Rahim, N., & Selvaraj, J. (2007). Implementation of Hysteresis Current Control for Single-Phase Grid Connected Inverter. *IEEE International Conference on Power Electronics and Drive Systems (PEDS) at Bangkok, Thailand*, (L), 1097–1101.

Kumar.D, S., Indira, R. N. D., & Ashok, R. (2015). Design and Analysis of Single Phase Grid Connected Inverter. *International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)*, 1245–1251.

Kuo, Y., Liang, T., & Chen, J. (2001). Novel Maximum-Power-Point-Tracking Controller for Photovoltaic Energy Conversion System. *IEEE Transactions on Industrial Electronics*, *48*(3), 594–601.

Kyritsis, A. C., Papanikolaou, N. P., & Tatakis, E. C. (2007). A novel Parallel Active Filter for Current Pulsation Smoothing on Single Stage Grid-connected AC-PV Modules. *IEEE Power Electronics and Applications*.

Kyritsis, A. C., Papanikolaou, N. P., & Tatakis, E. C. (2008). Enhanced Current Pulsation Smoothing Parallel Active Filter for Single Stage Grid-Connected AC-

PV Modules. *IEEE International Power Electronics andMotion Control Conference (EPE-PEMC)*, 1287–1292.

Lacerda, V. S., Barbosa, P. G., & Braga, H. A. C. (2010). A Single-Phase Single-Stage , High Power Factor Grid-Connected PV System, with Maximum Power Point Tracking. *IEEE International Conference on Industrial Technology (ICIT) at Vina Del Mar, Chile*, 871–877.

Lakshmanan, S. A., & Jain, A. (2015). Design and Analysis of Current Controllers with Active Damped LCL Filter for Three-Phase Grid Connected Solar PV System. *IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA) at Bangkok, Thailand*.

Lettl, J., Bauer, J., & Linhart, L. (2011). Comparison of Different Filter Types for Grid Connected Inverter. *Progress In Electromagnetics Research Symposium Proceedings*, 1426–1429.

Li, H., & Abu-Qahuoq, J. (2013). Control of Cascaded Inverters with MPPT for Grid-Connected Photovoltaic Generators. *IEEE International Telecommunications Energy Conference "Smart Power and Efficiency" (INTELEC) at Hamburg, Germany*, 620–625.

Li, X., & Balog, R. S. (2015). PLL-less Robust Active and Reactive Power Controller for Single Phase Grid-Connected Inverter with LCL Filter. *IEEE Applied Power Electronics Conference and Exposition (APEC) at Charlotte, NC, USA*, 2154–2159.

Liang, T. J., Kuo, Y. C., & Chen, J. F. (2001). Single-stage photovoltaic energy conversion system. *IEEE Proceeding Electronic Power*, *148*, 339–344.

Libo, W., Zhengming, Z., Jianzheng, L., Shu, L., & Liqiang, Y. (2005). Modified MPPT Strategy Applied in Single-Stage Grid-Connected Photovoltaic System. *IEEE International Conference on Electrical Machines and Systems (ICEMS) at Nanjing, China*, *2*, 1027–1030.

Liu, F., Kang, Y., Zhang, Y., & Duan, S. (2008). Comparison of P&O and Hill Climbing MPPT Methods for Grid-Connected PV Converter. *IEEE Conference on Industrial Electronics and Applications (ICIEA) at Singapore*, 804–807.

Liu, T., Hao, X., Yang, X., Liu, J., Zhang, B., & Huang, L. (2012). A Novel Current Dual-loop Control Strategy for Three-phase Grid-Connected VSI with LCL filter. *IEEE International Power Electronics and Motion Control Conference (IPEMC) at Harbin, China*, 626–630.

Lyden, S., Haque, M. E., Gargoom, A., Negnevitsky, M., & Muoka, P. I. (2012). Modelling and Parameter Estimation of Photovoltaic Cell. *IEEE Australasian Universities Power Engineering Conference (AUPEC) at Bali, Indonesia*.

Mahamudul, H., Saad, M., & Henk, I. (2012). A Modified Simulation Method of Photovoltaic Module in Simulink Environment. *IEEE International Conference on Electrical & Computer Engineering (ICECE) at Dhaka, Bangladesh*, (1), 607–610.

Meneses, D., Blaabjerg, F., Garcia, O., & Cobos, J. A. (2013). Review and Comparison of Step-Up Transformerless Topologies for Photovoltaic AC-Module Application. *IEEE Transactions on Power Electronics*, *28*(6), 2649–2663.

Mitchell, K., Nagrial, M., & Rizk, J. (2005). Simulation and Optimisation of Renewable Energy Systems. *International Journal of Electrical Power & Energy Systems*, *27*(3), 177–188. doi:10.1016/j.ijepes.2004.10.001

Mosa, M., Abu-rub, H., Ahmed, M. E., Kouzou, A., & Rodríguez, J. (2013). Control of Single Phase Grid Connected Multilevel Inverter Using Model Predictive Control. *IEEE International Conference on Power Engineering, Energy and Electrical Drives (POWERENG) at Istanbul, Turkey*, (May), 13–17.

Nachiappan, A., Sundararajan, K., & Malarselvam, V. (2012). Current Controlled Voltage Source Inverter Using Hysteresis Controller And PI Controller. *IEEE International Conference on Power, Signals, Controls and Computation (EPSCICON) at Thrissur, Kerala, India*.

Namboodiri, A., & Wani, H. S. (2014). Unipolar and Bipolar PWM Inverter. *International Journal for Innovative Research in Science & Technology*, *1*(7).

Nan, J., Shiyang, H., Guangzhao, C., Suxia, J., & Dongyi, K. (2016). Model-Predictive Current Control of Grid-Connected Inverters for PV Systems. *IEEE International Conference on Renewable Power Generation (RPG) at Beijing, China*.

Natarajan, P., Ramabadran, R., & Muthu, R. (2012). Application of Circuit Model for Photovoltaic Energy Conversion System. *International Journal of Photoenergy*, *2012*. doi:10.1155/2012/410401

Nicastri, A., & Nagliero, A. (2010). Comparison and Evaluation of The PLL Techniques for The Design of The Grid-Connected Inverter Systems. *IEEE International Symposium on Industrial Electronics (ISIE) at Bari, Italy*, 3865–3870.

Noor, S. Z. M., Omar, A. M., Mahzan, N. N., & Ibrahim, I. R. (2013). A Review of Single-Phase Single Stage Inverter Topologies for Photovoltaic System. *IEEE Control and System Graduate Research Colloquium*, 19–20.

Patel, H., & Agarwal, V. (2009). A Single-Stage Single-Phase Transformer-Less Doubly Grounded Grid-Connected PV Interface. *IEEE Transactions on Energy Conversion*, *24*(1), 93–101.

Patel, J., & Sharma, G. (2013). Modeling and Simulation of Solar Photovoltaic Module Using Matlab/Simulink. *International Journal of Research in Engineering and Technology*, *2*(3), 225–228.

Perera, B. K., Puiikanti, S. R., Ciufo, P., & Perera, S. (2012). Simulation Model of a Grid-Connected Single-Phase Photovoltaic System in PSCAD/EMTDC. *IEEE International Conference on Power System Technology (POWERCON) at Auckland, New Zealand*.

Raghuwanshi, S. S., & Gupta, K. (2015). Modeling of a Single-Phase Grid-Connected Photovoltaic System Using MATLAB / Simulink. *IEEE International Conference on Computer, Communication and Control (IC4) at Indore, India*.

Rajeev, M., & Agarwal, V. (2016). Closed loop Control of Novel Transformer-less Inverter Topology for Single Phase Grid Connected Photovoltaic system. *IEEE Power and Energy Conference at Illinois (PECI).*

Ramos-Hernanz, J. ., Campayo, J. J., Larranaga, J., Motrico, J., Gamiz, U. F., Zulueta, E., … Barambones, O. (2012). Two Photovoltaic Cell Simulation Models in Matlab/Simulink. *International Journal on "Technical and Physical Problems of Engineering"*, *4*(March), 45–51.

Rathika, P., & Devaraj, D. (2010). Fuzzy Logic – Based Approach for Adaptive Hysteresis Band and DC Voltage Control in Shunt Active Filter. *International Journal of Computer and Electrical Engineering*, *2*(3).

Raviraj, V. S. C., & Sen, P. C. (1997). Comparative Study of Proportional – Integral, Sliding Mode, and Fuzzy Logic Controllers for Power Converters. *IEEE Transactions on Industry Applications*, *33*(2), 518–524.

Renzhong, X., Lie, X., Junjun, Z., & Jie, D. (2013). Design and Research on the LCL Filter in Three-Phase PV Grid-Connected Inverters. *International Journal of Computer and Electrical Engineering*, *5*(3), 3–6. doi:10.7763/IJCEE.2013.V5.723

Rezaei, M. A., Farhangi, S., & Farivar, G. (2010). An Improved Predictive Current Control Method for Grid-Connected Inverters. *IEEE Power Electronic & Drive Systems & Technologies Conference (PEDSTC) at Tehran, Iran*, 1–5.

Ruiz, G. E. M., Muñoz, N., & Cano, J. B. (2015). Modeling, Analysis and Design Procedure of LCL Filter for Grid Connected Converters. *IEEE Power Electronics and Power Quality Applications (PEPQA)*, 0–5.

Sahu, P. K., Shaw, P., & Maity, S. (2015). Modeling and Control of Grid-Connected DC/AC Converters for Single-Phase Micro-inverter Application. *EEE India Conference (INDICON).*

Salmi, T., Bouzguenda, M., Gastli, A., & Masmoudi, A. (2012). MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell. *International Journal Of Renewable Energy Research (IJRER) at*, *2*(2).

Sandeep, N., Murthy, M. K., & Kulkarni, P. S. (2014). Single-Phase Grid-Connected Photovoltaic System Based on Ripple Correlation Control Maximum Power Point Tracking. *IEEE Students' Conference on Electrical, Electronics and Computer Science at Bhopal, India*, 1–6.

Sandeep, N., & Udaykumar, R. Y. (2015). Single-Phase Modular Multilevel Inverter based Grid-Connected Photovoltaic System. *IEEE India Conference (INDICON)*, 1–6.

Sekhar, P. C., Pavan, B., Goud, K., Shanmugasundari, C., Chandrababu, P., & Kiran, S. H. (2015). Single-Phase Single-Stage Transformer Less Grid Connected PV System. *International Journal of Electric Power and Energy*, *1*(1), 1–5.

Shahi, T., & Singh, K. P. (2014). Mitigation of Voltage Sags/Swells to Enhance Power Quality of Distribution System Using a Custom Power Device (DVR). *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *3*(7), 10686–10694. doi:10.15662/ijareeie.2014.0307057

Shankar, G. (2015). THD Analysis of Various PWM Switching Techniques and Comparative Study of Symmetrical 9 Level Inverter & Asymmetrical 31 Level Inverter. *International Journal of Electronics, Electrical and Computational System*, *4*(May), 97–108.

Shukla, A., Khare, M., & Shukla, K. N. (2015). Modeling and Simulation of Solar PV Module on MATLAB / Simulink. *International Journal of Innotivative Research in Science, Engineering and Technology*, *4*(1), 18516–18527. doi:10.15680/IJIRSET.2015.0401015

Singh, R., & Pandit, M. (2013). Analysis of Photovoltaic Cells with Closed Loop Boost Converter. *International Journal of Advances in Engineering & Technology*, *6*(1), 304–315.

Song, J. (2011). Simulation of Grid-Connected Photovoltaic System.

Sripipat, W., & Po-ngam, S. (2014). Simplified Active Power and Reactive Power Control with MPPT for Single-Phase Grid-Connected Photovoltaic Inverters. *IEEE International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON) at Nakhon Ratchasima, Thailand*, 4–7.

Stala, R., Koska, K., & Stawiarski, L. (2011). Realization of Modified Ripple-Based MPPT in a Single-Phase Single-Stage Grid-Connected Photovoltaic System. *IEEE International Symposium on Industrial Electronics (ISIE) at Gdansk, Poland*, 1106–1111.

Suhara, E. M., & Nandakumar, M. (2015). Analysis of Hysteresis Current Control Techniques for Three Phase PWM Rectifiers. *IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES) at Kozhikode, India*, 5–9.

Teng, Y., Xiong, C., Li, C., Hui, Q., & Zhu, Y. (2015). Grid-Connected PV Power Plant LCL Filter Based on PI and PR Control Strategy. *IEEE Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, (111).

Teodorescu, R., & Blaabjerg, F. (2004). A New Control Structure for Grid-Connected LCL PV Inverters with Zero Steady-State Error and Selective Harmonic Compensation. *IEEE Applied Power Electronics Conference and Exposition (APEC) at Anaheim, CA, USA*, *00*(C), 580–586.

Thao, N. G. M., & Uchida, K. (2013). Control The Photovoltaic Grid-Connected System Using Fuzzy Logic and Backstepping Approach. *IEEE Asian Control Conference (ASCC) at Istanbul, Turkey*.

Thomas, M. S., & Nisar, A. (2015). Data-Driven Modeling and Simulation of PV Array. *IEEE*.

Tipsuwanporn, V., Charoen, A., Numsomran, A., & Phipek, K. (2011). A Single-Phase PWM Inverter Controlling Base on PLL Technique. *IEEE SICE Annual Conference at Tokyo, Japan*, 1178–1183.

Tofoli, F. L., Schönell, J. C., Gallo, C. A., Manuel, S., & Sanhueza, R. (2009). A Low Cost Single-Phase Grid-Connected Photovoltaic System With Reduced Complexity. *IEEE Brazilian Power Electronics Conference*, 1033–1038.

Variath, R. C., Nielsen, O. N., & Sunsil, A. S. (2010). A Review of Module Inverter Topologies Suitable for Photovoltaic Systems. *IEEE Power Electronics Conference (IPEC) at Singapore*.

Vázquez, G., Rodriguez, P., & Ordoñez, R. (2009). Adaptive Hysteresis Band Current Control for Transformerless Single-Phase PV Inverters. *IEEE Industrial Electronics at Porto, Portugal*, 173–177.

Verma, V., & Kumar, A. (2013). [ic] Grid Connected Single Phase Rooftop PV System with Limited Reactive Power Supply. *IEEE International Conference on Power, Energy and Control (ICPEC) at Sri Rangalatchum Dindigul, India*, (Vi), 39–43.

Wang, J., Peng, F. Z., Anderson, J., & Joseph, A. (2004). Low Cost Fuel Cell Converter System for Residential Power Generation. *IEEE Transactions on Power Electronics*, *19*(5), 1315–1322.

Wang, Y., & Yu, X. (2013). Comparison Study of MPPT Control Strategies for Double-stage PV Grid-connected Inverter. *IEEE Industrial Electronics Society at Vienna, Austria*, 1561–1565.

Wessels, C., Dannehl, J., & Fuchs, F. W. (2008). Active Damping of LCL-Filter Resonance based on Virtual Resistor for PWM Rectifiers – Stability Analysis with Different Filter Parameters. *IIEEE Power Electronics Specialists Conference (PESC) at Rhodes, Greece*.

Wu, W., He, Y., Tang, T., & Blaabjerg, F. (2013). A New Design Method for the Passive Damped LCL and LLCL Filter-Based Single-Phase Grid-Tied Inverter. *IEEE Transactions on Industrial Electronics*, *60*(10), 4339–4350.

Xingwu, Y., Hongchao, J., & Wei, G. (2014). Model Predictive Control of Single Phase Grid-Connected Inverter. *IEEE Asia-Pacific Power and Energy Engineering Conference (APPEEC) at Hong Kong, China*, (51207086).

Yan, Z., Shanxu, D., Fei, L., & Jinjun, Y. (2008). Research on Digital Implementation of Proportional-Resonant Controller Based on A Three-Phase PV Grid-Connected System. *IEEE International Conference on Electrical Machines and Systems (ICEMS) at Wuhan, China*, 2746–2749.

Yang, L., Xiong, C., Teng, Y., Hui, Q., & Zhu, Y. (2015). Harmonic Current Suppression of Grid-connected PV Based on PR Control Strategy. *IEEE International Conference on Intelligent Systems Design and Engineering Applications (ISDEA) at Guiyang, China*, 2–5. doi:10.1109/ISDEA.2015.114

Yu, B., & Chang, L. (2005). Improved Predictive Current Controlled PWM for Single-Phase Grid-Connected Voltage Source Inverters. *IEEE Power Electronics Specialists Conference (PESC) at Recife, Brazil*, 231–236.

Zakzouk, N. E., Abdelsalam, A. K., Helal, A. A., & Williams, B. W. (2014). DC-Link Voltage Sensorless Control Technique for System. *IEEE International Energy Conference (ENERGYCON) at Cavtat, Croatia*, 58–64.

Zammit, D., Staines, C. S., & Apap, M. (2014). Comparison between PI and PR Current Controllers in Grid Connected PV Inverters. *International Scholarly and Scientific Research & Innovation*, *8*(2), 221–226.

Zamodzki, R., Stein, C. M. O., & Carati, E. G. (2015). Evaluation of Control Strategies for LCL Grid-Tied Distributed Generation Systems. *IEEE Brazilian Power Electronics Conference and Southern Power Electronics Conference (COBEP/SPEC)*.

Zeng, G., & Liu, Q. (2009). An Intelligent Fuzzy Method for MPPT of Photovoltaic Arrays. *IEEE International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM) at Tunis, Tunisia*, 356–359. doi:10.1109/ISCID.2009.235

Zhang, C., Dragicevic, T., Vasquez, J. C., & Guerrero, J. M. (2014). Resonance Damping Techniques for Grid-Connected Voltage Source Converters with LCL filters – A Review. *IEEE International Energy Conference (ENERGYCON) at Cavtat, Croatia*.

Zhang, D., Niu, H. C., & Jiang, M. (2013). Proportional Resonant-controlled Grid Tied Inverter with L-C Resonant Filter and its Comparison with Inverter with LCL Filter. *IEEE Region 10 Conference (TENCON) at Sydney, NSW, Australia*, 272–276.

Zhang, N., Tang, H., & Yao, C. (2014). A Systematic Method for Designing a PR Controller and Active Damping of the LCL Filter for Single-Phase Grid-Connected PV Inverters. *Energies*, *7*(6), 3934–3954. doi:10.3390/en7063934

Zhang, Y., & Lin, H. (2011). Simplified Model Predictive Current Control Method of Voltage-Source Inverter. *IEEE International Conference on Power Electronics and ECCE Asia (ICPE & ECCE) at Jeju, South Korea*.

Zhao, P., Huang, W., & Zhou, Y. (2012). Single-Stage Boost Inverter Applied to Photovoltaic System. *IEEE Power and Energy Engineering Conference (APPEEC)*, (50977045), 0–3.

Zhao, Y., Zhang, Y., Wang, D., & Zhan, J. (2009). The Circuit Topology for Single-Phase Grid-Connected System and The Control Technology on Converters. *IEEE International Conference on Sustainable Power Generation and Supply (SUPERGEN) at Nanjing, China*, 1–5.

Zhong, X., Hong, L., Chen, X., & Chen, G. (2012). Design and Implementation of Compound Current Control Strategy for Improved LCL-based Shunt Active Power Filter. *EEE Industrial Electronics Society*, 339–344.

Zhou, H., Tong, C., Mao, M., & Gao, C. (2010). Development of Single-Phase Photovoltaic Grid-connected Inverter Based on DSP Control. *IEEE International Symposium on Power Electronics for Distributed Generation Systems at Hefei, China*, 650–653.

Zmood, D. N., & Holmes, D. G. (2003). Stationary Frame Current Regulation of PWM Inverters with Zero Steady-State Error. *IEEE Transactions on Power Electronics, 18*(3), 814–822.

Zope, P. H., Bhangale, P. G., Sonare, P., & Suralkar, S. R. (2012). Design and Implementation of Carrier Based Sinusoidal PWM Inverter. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *1*(4), 230–236.